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Resource Allocation for Air Traffic Controllers using Dynamic Airspace Configuration

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Abstract—One aspect of the Air Traffic Management (ATM) system being used in the United States that requires further development is air traffic resource allocation. Currently, the National Airspace (NAS) is divided into centers, each of which is controlled by air traffic control centers; with each of the centers further divided into sectors assigned to an air traffic controller. These sectors are static in configuration and are not changed dynamically: it would be desirable to more evenly distribute air controllers' workloads when some sectors become overloaded with too much air traffic and others are not. This could be achieved by having automated systems that considers projected traffic demand and Air Traffic Control (ATC) resources to reconfigure airspace in order to balance the controllers' workload. The implementation of such a dynamic approach is a goal of the Dynamic Airspace Configuration (DAC) concept for the NextGen ATM system. DAC will include one or more mechanisms to dynamically reallocate resources, by resectorizing the airspace to more evenly balance the air traffic controllers' load. This paper discusses current DAC research and the future goals for this emerging field.

Index Terms—dynamic, airspace, resource, allocation, optimization

I. Introduction

The continental United States air space is currently subdivided into twenty Air Route Traffic Control Centers (ARTCCs, or just Centers); these air spaces are further divided into a total of approximately 600 sectors. Each sector is monitored by one or more human controllers. Today's sectors have progressively evolved overtime according to flight trajectory patterns and aircraft volume; with minor changes occasionally made to accommodate variations in the airspace demand. The Federal Aviation Administration (FAA) currently employs about 15,000 controllers managing roughly 60,000 daily flights, interconnecting about 2,000 airports [1]. The National Airspace System (NAS) is forecasted to become congested because of the predicted three fold increase in air traffic in the next two decades [2].

The current sector-based airspace configuration remains static throughout its operation and is not changed dynamically to meet the high traffic and limited Air Traffic Control (ATC) resources. It is desirable to have automated systems and decision support tools (DST) that considers projected traffic demand and ATC resource to reconfigure airspace in order to balance the workload of the controllers. This will not only ensure safety, but also increased utilization of airspace and thus decreased delays.

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II. DAC as NextGen Concept

The Interagency Joint Planning and Development Office (JPDO) is in charge of developing the 2025 Next Generation Air Transportation System (NextGen), including the research required to implement it. One of the technical goals for NextGen is to increase capacity through dynamic allocation of airspace structure and controller resources [3]; this dynamic reconfiguration of airspace is referred to as Dynamic Airspace Configuration (DAC). The goal of DAC is to help balance demand and capacity, and so reduce the workload of the individual air traffic controller.

The DAC algorithms can be categorized as dynamic resource allocation problems because they are dealing with the reallocation of resources in a system with a continually changing configuration over a period of time. As in traditional dynamic resource allocation problems, with DAC algorithms the airplanes represent tasks and the resources to be assigned to tasks are represented by the airspace (sectors). In these problems the state of the tasks (airspace) is continuous, because of the different numbers of planes being in the airspace at different times. The secondary resource allocation problem is balancing the workload of air traffic controllers where, in this case, the controllers are resources and the sectors are tasks to be assigned [4].

III. Current DAC Research

There are a number of algorithms that have been developed for DAC resectorization. These can be grouped into airspace partitioning, functional space partitioning, and iterative (incremental) algorithms.

A. *Airspace Partitioning*

Algorithms in this group operate directly on the airspace and are considered to be optimization problems. The Voronoi Diagram and Genetic algorithm uses the Voronoi diagram to divide the airspace into subdivisions, followed by the genetic algorithm conducting a guided random search "based on the principals of genetic inheritance and Darwinian evolution" [5]. The goal is to maximize the gap between the capacity and peak aircraft count of each sector, with the number of sectors being equal to the number of Voronoi diagram generating points used [6]. "Voronoi diagrams accomplish the graph partition, which then needs to be optimized. By defining a multi-objective cost, the combination of the Genetic algorithm and iterative deepening algorithm solves the optimization problem" [6].

B. *Functional Space Partitioning*

These algorithms include two steps: airspace transformation to a network, followed by network partitioning. Examples are the Weighted-Graph Approach [7] and Flight Clustering algorithm and Computational Geometry algorithm [8].

The Weighted-Graph algorithm is used to "partition airspace into smaller regions based on a peak traffic-counts metric" [7]. The initial setup consists of creating a network flow graph, followed by an occupancy grid composed of cells of specified size for the divided airspace and finally assigning the grid cells to the nodes of the network flow graph. The required weights are equal to the number of planes in each grid cell at a given time. Spectral bisection is used to separate the sub-graph with the maximum weight into two sub-graphs, and this is then repeated recursively until the final set of sub-graphs is obtained. The resulting grid cells then give the required sector geometry [7].

The Clustering and Computational Geometry algorithm divides airspace into clusters, by grouping similar flight routes together. Sector boundaries are formed around these groupings, with the size of the groupings been equal to an assigned maximum workload. This algorithm uses "Dynamic Density factors to control the clustering of flight route segments" [8]. This approach can be considered a constrained clustering problem.

The algorithm for defining critical points for DAC [9] can be used to identify nodes for the weight-graph algorithm and clusters for the Clustering and Computational Geometry algorithm.

C. *Iterative (Incremental)*

Examples of these are Combining Airspace Sectors for the Efficient Use of Air traffic control resources [10] algorithm and the Dynamic Fix Posting Area (FPA) algorithm [11]. FPA can be considered as an airspace portioning algorithm as well. They are formulated as constrained satisfaction problems. Heuristic has been developed to reconfigure a baseline airspace as long as they satisfy specified constrains.

The goal is to ensure that the resulting configured airspace is not significantly different than the baseline configuration, so that its implementation does not required additional controller training.

The Dynamic FPA algorithm operates on predefined airspace and is one form of Flexible Airspace Management [11]. It works well in 3D space, allowing for both boundary changes and also sector combinations as required. Furthermore, adjustments in airspace occur in pre-defined, discrete steps rather than continuous ones. By extending the FPA concept into the Dynamic FPA realm, it allows for the implementation into DAC methods. By doing so the Dynamic FPA concept provides a possible bridge from the current NAS airspace design to future NAS concepts (e.g., Flexible Airspace Management and Dynamic Resectorization), while having the potential of significantly increasing the flexibility and capacity of the airspace. The Dynamic FPA method and airspace boundary optimization methods could be combined into a two-step airspace design process. The initial airspace configuration can be determined by optimization algorithms based on typical traffic data, the results from which could be used as a starting point for the Dynamic FPA design [11]. The Dynamic FPA method was developed with an assumption that the structure of the airspace is predefined, and can be considered an Airspace Partitioning algorithm, because they partition airspace directly.

Airspace Combining Sectors algorithm is implemented with the assumption of controller operating only with sectors in the "same area of specialization" [10]. This algorithm is based on the "predicted excess capacity of sectors. Such a measure has two components. The first is a predicted measure of the utilization of a sector. "The second is a measure of the maximum possible safe utilization of a sector, which is also referred to as the capacity of a sector" [10]. This algorithm is using a "maximum instantaneous aircraft count to measure the utilization of a sector and a Monitor Alert Parameter (MAP) value to indicate its capacity" [10].

IV. Future Research

There are a number of issues and resource questions that need to be addressed with regards to NextGen goals from the ATM point of view

- How often an airspace needs to be reconfigured,
- What conditions and criteria need to be met to trigger reconfiguration,
- How much of the NextGen capabilities such as automation, Communication, Navigation and Surveillance (CNS) and Decision Support Tools (DST) need to be considered in the DAC algorithm development,
- How does NextGen traffic affect the complexity of DAC and realities of ATM operations? NextGen airspace considers a three-fold increase in air traffic in 2025 and beyond [2]. Under such traffic conditions, Traffic Flow Management (TFM) policies will be critical to the mitigation or distribution of the flight delays and hence, the need to consider airspace configuration. Furthermore, the airspace configuration algorithms need to take TFM policies in the account.

Although a number of algorithms have been discussed in the literature, they need to be evaluated to address the above resource questions for their applicability to NextGen air traffic.

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